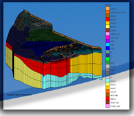
Performance Study of

Parallel Algorithms in pWASH123D

System-Wide Water Resources Program (SWWRP)



Background

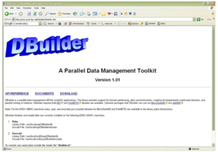
Based on the first-principle, physics-based numerical model WASH123D, the U.S. Army Engineer Research and Development Center has been developing a parallel watershed code, pWASH123D, and its graphical user interface in the Department of Defense Groundwater Modeling System in collaboration with Brigham Young University since January 2003. To date, pWASH123D has a complete suite of water flow simulations in a watershed system that can be conceptualized as a combination of one-dimensional (1-D) channel network, 2-D overland regimes, and 3-D subsurface media. This poster presents the outcome of a performance study on the parallel algorithms currently employed in pWASH123D. The experimental area includes a 570-square-mile domain covering most of the land south of the Tamiami Trail in South Florida and north of the Gulf of Mexico, Florida Bay, and Biscayne Bay. This area was discretized to three mesh resolutions—coarse, medium, and fine meshes—to identify the performance bottleneck. Problems were designed to investigate the parallel strategy for the 1-D component.

pWASH123D

- Solve the cross-sectional area-averaged diffusive wave equation with the semi-Lagrangian finite element method (FEM) for 1-D channel flow.
- Solve the depth-averaged diffusive wave equation with the semi-Lagrangian FEM for 2-D overland flow.
- Solve the Richards' equation for variably saturated porous media with the Galerkin FEM for 3-D subsurface flow.
- Enforce the continuity of flux and/or state variables (e.g., water head, concentration) on the interface of two media.
- Consider rainfall, evapotranspiration, rule-controlled flow, injection/withdrawal as sources/sinks at respective media.
- Employ different time intervals for computations in different dimensions to resolve various flow processes ($\Delta t_{3D} \geq \Delta t_{2D} \geq \Delta t_{1D}$, e.g., Δt_{3D} = 30 m, Δt_{2D} = 5 s, Δt_{1D} = 0.5 s used in this study).
- Implement independent domain partitioning, coherent data structures, and interactions between domains.

Parallel Data Management Toolkit

ERDC MSRC Major Shared Resource Center



Hierarchical Data Structures

Coupling Algorithm

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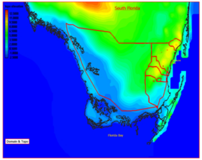
Foreach 3-D flow time-step (Δt3D) do
  Foreach 3-D coupling/nonlinear iteration do
   Foreach 2-D flow time-step (Δt2D) do
     Incorporate infiltration/seepage for 2-D/3-D coupling
     Foreach 2-D coupling/nonlinear iteration do
      Foreach 1-D flow time-step (Δt1D) do
        Incorporate infiltration/seppage for 1-D/3-D coupling
        Incorporate infiltration/seepage for 1-D/2-D coupling
        Foreach 1-D coupling iteration loop do
          Solve linearized 1-D flow equation
        Endfor
        Incorporate infiltration/seepage for 1-D/2-D coupling
        Solve linearized 2-D flow equation
      Endfor
     Endfor
   Endfor
   Incorporate infiltration/seepage for 1-D/3-D coupling
   Incorporate infiltration/seepage for 2-D/3-D coupling
   Solve linearized 3-D flow equation
  Endfor
Endfor
```

Parallelization Strategy

- DBuilder is used in both 2- and 3-D computation to balance computational load on each processor.
- Each processor reads complete 1-D channel information and executes 1-D computation without partitioning to avoid excessive run time overhead from data exchange among processors.

Test Example



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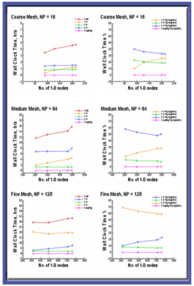
Computational Meshes

NP = No. of processors
ND = No. of nodes
NE = No. of elements
NR = No. of canal reaches

Mesh ID	Coarse Mesh		Medium Mesh		Fine Mesh	
NP	16		64		128	
Components	ND	NE	ND	NE	ND	NE
2-D	8,487	16,583	42,941	84,996	101,148	200,935
3-D	59,409	99,498	558,233	1,019,952	1,314,924	2,411,220
1-D	ND	NR	ND	NR	ND	NR
Case 1	89	1	206	1	316	1
Case 2	127	2	298	2	492	2
Case 3	200	4	463	4	710	4
Case 4	214	5	495	5	760	5



Results

- The wall-clock time for 1-D computation is approximately proportional to the number of 1-D nodes included in the simulation, which results in the increase of both total wall-clock time and the wall-clock time percent for 1-D computation.
- The wall-clock time for 2- and 3-D computations basically does not vary with the number of 1-D nodes.
- With the current parallelization strategy in pWASH123D, it is obvious that the fewer 1-D nodes considered for computation, the less time spent for 1-D computation.
- The time spent in couplers is negligible when compared with that spent in 1-, 2-, or 3-D computation.

Summary and Future Plans

The 1-D computation significantly takes up a portion of overall wall-clock time of simulations when using a larger number of processors with the current parallelization strategy. This result is also strongly related to the multiple time-step coupling algorithm employed to resolve various physical processes. An autonomous approach, which can guarantee convergence of the nonlinear system using larger time-step sizes, will highly benefit such a parallel watershed model. It is also worthwhile to investigate time-space parallelism on the lower dimensional domains.